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Effects of Simulated Acid Rain on Yield Response of Two Soybean Cultivars

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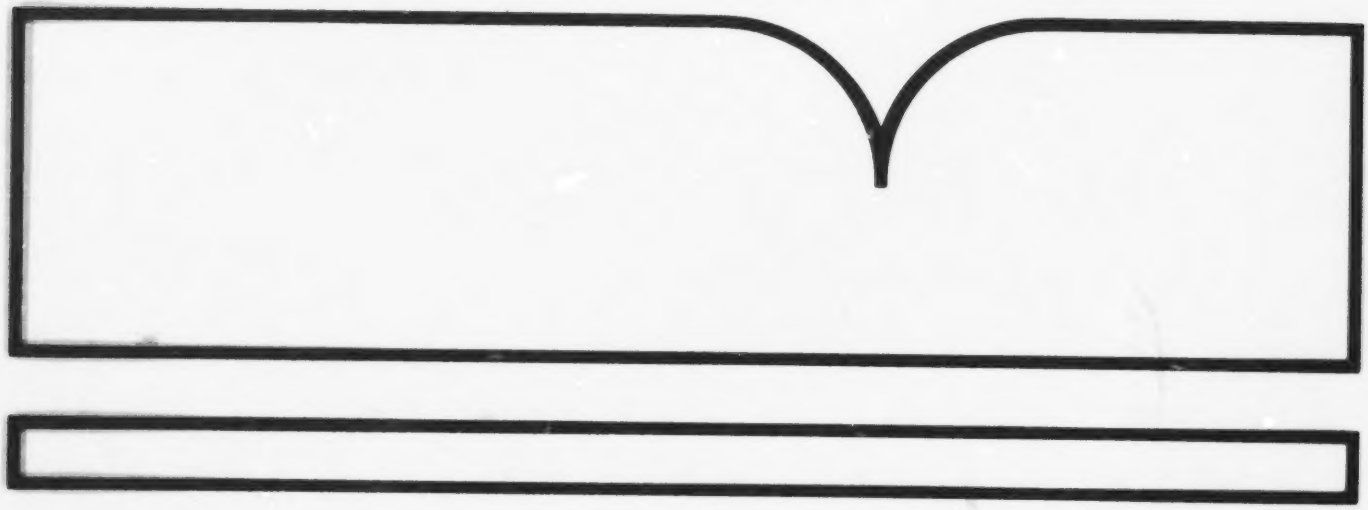

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16. ABSTRACT

An important component of the effects of acid rain on our ecosystem is its impact on the yield of agricultural crops. Field experiments were conducted for 3 yr to determine the effects of simulated acid rain on seed yield of two soybean [Glycine max (L.) Merr.] cultivars, 'Amsoy 71' and 'Williams 82'. Soybeans were grown on a Flanagan silt loam (fine, montmorillonitic, mesic Aquic Argiudoll) and protected from ambient rainfall by movable rain exclusion shelters. Plants were treated biweekly with simulated rain of pH 5.6, 4.6, 4.2, 3.8, 3.4, and 3.0. For Amsoy 71 there was a linear decrease in yield with increasing rainfall acidity for 1 of 3 yr but no significant effects for the other two. Thus acid rain appears to reduce the yield of some soybean cultivars slightly but this effect is not consistent from year to year. Amsoy 71 and Williams 82 soybean treated with the most acidic rain, pH 3.0, resulted in average yields for the 3 yr of the study of approximately 3 and 4% lower than the average yields for the other treatments, respectively. However, calculations from the response functions developed have shown that at current levels of rainfall acidities the effects on yield are very small. With an increase in rainfall acidity of 50% in Illinois the predicted yield decrease for Amsoy 71 and Williams 82 soybean would be less than 1%. Similarly the expected increase in yield of these cultivars would be 1%. Similarly the expected increase in yield of these cultivars would be 1% or less if acidity in the rainfall were reduced by 50%. While there may be beneficial effects of reduced S and N oxide emissions, these results suggest the resultant lower rainfall acidities are not likely to produce noticeable changes in yield of soybean.

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ABSTRACT

An important component of the effects of acid rain on our ecosystem is its impact on the yield of agricultural crops. Field experiments were conducted for 3 yr to determine the effects of simulated acid rain on seed yield of two soybean [*Glycine max* (L.) Merr.] cultivars, 'Amsoy 71' and 'Williams 82'. Soybeans were grown on a Flanagan silt loam (fine, montmorillonitic, mesic Aquic Argiudoll) and protected from ambient rainfall by movable rain exlusion shelters. Plants were treated biweekly with simulated rain of pH 5.6, 4.6, 4.2, 3.8, 3.4, and 3.0. For Amsoy 71 there was a linear decrease in yield with increasing rainfall acidity for 1 of 3 yr but no significant effects for the other two. Thus acid rain appears to reduce the yield of some soybean cultivars slightly but this effect is not consistent from year to year. Amsoy 71 and Williams 82 soybean treated with the most acidic rain, pH 3.0, resulted in average yields for the 3 yr of the study of approximately 3 and 4% lower than the average yields for the other treatments, respectively. However, calculations from the response functions developed have shown that at current levels of rainfall acidities the effects on yield are very small. With an increase in rainfall acidity of 50% in Illinois the predicted yield decrease for Amsoy 71 and Williams 82 soybean would be less than 1%. Similarly the expected increase in yield of these cultivars would be 1% or less if acidity in the rainfall were reduced by 50%. While there may be beneficial effects of reduced S and N oxide emissions, these results suggest the resultant lower rainfall acidities are not likely to produce noticeable changes in yield of soybean.

Additional index words: Glycine max **(L.) Merr., Rain exclusion shelters, Grain yields, pH, Sulfate, Nitrate.**

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An important objective of research concerned with the effects of acid rain on our ecosystem is to examine its impact on growth and yield of crops grown under standard agronomic conditions. Because soybean [*Glycine max* (L.) Merr] plants are an economically important crop in the USA, rainfall acidity (dose)-response functions for seed yields are needed to predict the overall impact of soybean yields of ambient rain and/or anticipated levels of acidity in rain. For experiments of this nature it is desirable to exclude ambient rainfall and to use standard agronomic practices with large numbers of replicates, large sample sizes, and appropriate statistical analyses in which differences in treatment means of less than 10% can be determined.

There have been numerous studies of the effects of simulated acid rain on soybean. More than 10 cultivars representing over five maturity groups have been subjected to some form of simulated acid rain in controlled environment and field experiments (Table 1). Several reviews on the effects of simulated acid rain on soybean have been published (Evans et al., 1984a; Irving, 1983; Jacobson, 1980, 1982).

[1] Contribution of the Dep. of Agronomy, Univ. of Illinois, Urbana, IL 61801. Part of a thesis submitted by the senior author in partial fulfillment of the requirements for Ph.D. degree. Received 12 Feb. 1987.

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Table 1. Soybean cultivars subjected to simulated acid rain treatments.

Cultivar	Maturity group	Reference
Amsoy 71	II	Evans & Curry, 1979 Evans & Lewin, 1981 Evans & Thompson, 1984 Evans et al., 1980, 1981, 1983, 1984b, 1985 Irving et al., 1984
Beeson	II	Evans et al., 1984b Jacobson et al., 1980 Troiano et al., 1982, 1983
Clark	IV	Keever & Jacobson, 1983
Davis	VI	Brewer & Heagle, 1983 Heagle et al., 1983 Norby & Luxmoore, 1983 Norby et al., 1985
Evans	0	Lee et al., 1981 Cohen et al., 1981
Hark	I	Lee et al., 1981 Cohen et al., 1981
Lee	VI	Shriner & Johnston, 1981
Norman	00	Lee et al., 1981 Cohen et al., 1981
OR-10	00	Lee et al., 1981 Cohen et al., 1981
Wells	III	Evans et al., 1984b Irving & Sowinski, 1981 Irving & Miller, 1980, 1981
Williams	III	Craker & Bernstein, 1984 Evans et al., 1984b Troiano et al., 1982, 1983

Statistically significant seed yield reductions for Amsoy 71 were reported in six separate field experiments conducted on Long Island, NY (Evans et al., 1980, 1981, 1983, 1984b, 1985). In 1982 and 1983 the same researchers showed that acidity treatments resulted in no statistically significant yield differences for Williams 79 (Evans et al., 1984b, 1985). Other work in Illinois indicated no significant yield reduction for Amsoy 71 (Irving et al., 1984). Yields of other soybean cultivars grown under different experimental conditions have been reported to be unaffected by simulated acid rain treatments (Irving, 1983; Heagle et al., 1983; Jacobson, 1980, 1982; Troiano et al., 1983).

This paper describes experiments that were performed to determine if seed yields of field-grown soybean (cultivars Amsoy 71 and Williams 82) were influenced by six treatments of simulated rain differing in levels of acidity. The experiments were conducted in Illinois, which receives rainfall with an average annual pH of 4.3; this pH is approximately 20 times more acidic than the theoretical pH (5.6) of unpolluted rainfall in equilibrium with atmospheric CO_2.

MATERIALS AND METHODS

Culture

Field studies were conducted during 1983, 1984, and 1985 at the University of Illinois Agronomy and Plant Pathology South Farm near Urbana, IL (40 °N Lat) on a Flanagan silt loam soil (fine, montmorillonitic, mesic Aquic Argiudoll). The soil had a cation exchange capacity of 21 $cmol_c\ kg^{-1}$ and the pH of the surface 15 cm of soil was approximately 6.1 (Alexander et al., 1974). Land used for the experiment had been planted in wheat (*Triticum aestivum* L.) in 1982. Wheat stubble was chisel plowed to a depth of approximately 25 cm in the fall of 1982. In the spring of 1983 the plot area was fertilized, tilled with a disc-harrow, field cultivator, and rototilled. Treflan (2,6-dinitro-*N*, *N*-dipropyl-4-(trifluoromethyl) benezenamine), a preemergence herbicide (Elanco, Greenfield, IN), was applied at a rate of 2.33 L ha^{-1} prior to rototilling. Based on soil analysis, annual soil amendments were applied including P and K at recommended rates of 56 and 112 kg ha^{-1}, respectively (Illinois Agronomy Handbook, 1982). Soybean followed corn (*Zea mays* L.) in a corn-soybean rotation for 1984 and 1985. Seedbed preparation for 1984 and 1985 included chiseling and rototilling.

Table 2. Experimental parameters.

Simulated rain pH values	5.6, 4.6, 4.2, 3.8, 3.4, and 3.0		
Frequency of application	2 $week^{-1}$		
Time of application	1600 to 1900 h		
Duration of application	32 min rain time (48 min total)		
Simulated rain intensity	1.95 cm h^{-1}		
Median droplet size	1.2 mm		
Total deposition per simulated rain	1.05 cm		
	1983	1984	1985
Planting date	27 May	13 June	22 May
First simulated rain	7 June	19 June	30 May
Last simulated rain	19 Sept.	28 Sept.	13 Sept.
Number of simulated rain events	31	30	31
Total depth of simulated rain per plot	32.6 cm	31.6 cm	32.6 cm

Table 3. Concentration of the background ions in the simulated rain and the total amount of each ion added.†

Ion	Concentration	Total amount added		
		1983	1984	1985
	mg L^{-1}	kg ha^{-1}		
Ca^{2+}	0.165	0.537	0.520	0.537
Mg^{2+}	0.035	0.114	0.110	0.114
K^+	0.031	0.101	0.098	0.101
Na^+	0.169	0.551	0.533	0.551
NH_4^+	0.258	0.840	0.813	0.840
Cl^-	0.107	0.349	0.337	0.349
PO_4^{3-}	0.007	0.023	0.022	0.023

† The following compounds were used to achieve the ionic balance: NaCl, $CaSO_4 \cdot 2H_2O$, $MgSO_4 \cdot 7H_2O$, K_2SO_4, $NaNO_3$, $(NH_4)_2SO_4$, H_3PO_4, and NH_4NO_3.

Genotypes

Soybean seeds (Amsoy 71 and Williams 82) were obtained from Illinois Foundation Seeds, Inc., Champaign, IL. The maturity grouping of Amsoy 71 and Williams 82 is II and III, respectively, and both cultivars have indeterminate growth habits. Seeds were hand planted on 27 May 1983, 13 June 1984, and 22 May 1985 (Table 2). The distance between rows was 0.51 m and the distance between plants was approximately 0.061 m. Plots were overplanted and thinned to achieve the desired population of about 321 000 plants ha^{-1}.

Rain Exlusion Shelters and Simulated Rain Chemistry

Experimental plots were protected from ambient rainfall by movable rain exclusion shelters (Oehmsen Plastic Greenhouses, Bohemia, Long Island, NY). A more detailed description of the rain exclusion shelters is given in another publication (Banwart et al., 1987). Each summer two rain exclusion shelters protected soybean plots and two protected corn plots. Effects of simulated acid rain on corn are reported in another publication (Banwart et al., 1987). The rain exclusion shelters covered the crops only during ambient rainfall events and when simulated rain was applied through a nozzle system mounted

Table 4. Concentration of hydrogen, sulfate, and nitrate in the simulated rain and the total amount of each ion added.

pH	Concentration			Total amount added					
				1983 and 1985			1984		
	H^+	NO_3^-	SO_4^{2-}	H^+	NO_3^-	SO_4^{2-}	H^+	NO_3^-	SO_4^{2-}
	mg L^{-1}			kg ha^{-1}					
5.6	0.0025	0.457	1.114	0.008	1.49	3.63	0.008	1.44	3.51
4.6	0.025	0.839	2.015	0.081	2.73	6.56	0.079	2.64	6.35
4.2	0.063	1.406	3.422	0.205	4.58	11.15	0.199	4.43	10.79
3.8	0.158	2.841	6.737	0.515	9.25	21.95	0.498	8.96	21.24
3.4	0.398	6.444	15.239	1.300	20.98	49.64	1.250	20.31	48.04
3.0	1.000	15.495	36.591	3.260	50.48	119.20	3.150	48.85	115.40

Table 5. Grain yields for inner and outer rows† and the paired *t*-test of their differences.

Row	1983	1984	Both years
	kg ha^{-1}		
Inner row yield	4150	3780	3990
Outer row yield	4120	3750	3960
Test			
T	0.48	0.43	0.63
Pr > T‡	0.63	0.67	0.53

† Inner rows have one cultivar on one side and the other cultivar on the other side. Outer rows have the same cultivar on both sides.
‡ The probability that the difference between the yield for the inner and the outer row for each cultivar in the main plot is equal to zero.

in the structures. The total amount of simulated rain added to the plots was equivalent to the average amount of rain obtained during the growing season in Urbana, IL, for the last 30 yr (NOAA, 1982). No supplemental irrigation was necessary.

The chemistry of the simulated rain and the method of application are discussed in more detail elsewhere (Banwart et al., 1987). The chemical composition and the total amount of each ion added over the course of the growing season are listed in Tables 3 and 4. The acidity of the simulated rain was adjusted with sulfuric and nitric acids at a constant sulfate/nitrate ratio of 3.1:1 on an equivalent basis.

Experimental Design

The experimental design consisted of a split plot with the main plot arranged in a randomized complete block design. The variable for the main plot was one of six simulated rain acidity levels and cultivar was the split plot variable. Each main plot consisted of six adjacent rows, 3.05 m in length, spaced 0.51 m apart. The harvest area consisted of all plants in the center 2.44 m of the middle four rows (Banwart et al., 1987). Two of the rows were of one cultivar and the other two rows were of the other cultivar. Each row was harvested and weighed separately, making it possible to evaluate any potential interference of growing one cultivar adjacent to the other cultivar in the experimental design employed in this study.

Statistical Analysis System (SAS), a computer software system for data analysis, was used for all the statistical analyses (SAS Inst. Inc., 1982). When appropriate, error A and error B of the split plot design were pooled to gain precision for testing treatment effects. The significance level selected for pooling was $\alpha = 0.25$ (Carmer et al., 1969).

Yield results were analyzed using four specific contrasts: (i) pH linear, (ii) pH quadratic, (iii) pH 3.0 vs. the average of the other five treatments, and (iv) pH 5.6 vs. the average of the other five treatments. If the pH linear or pH quadratic contrasts were significant, the other two contrasts were not meaningful. However, if the pH linear and pH quadratic contrasts were not significant, it was of interest to compare values at the two treatment extremes—pH 3.0, the most acidic treatment and pH 5.6, the control treatment. Since the pH treatment levels were unequally spaced, orthogonal coefficients for the contrasts were calculated using the method of Carmer and Seif (1963).

RESULTS AND DISCUSSION

Border Effects

Yield data were analyzed to test whether there was a border effect on seed yield. Each main plot contained three rows of one cultivar adjacent to three rows of the other cultivar. Since only the four center rows were harvested, one harvest row for each cultivar (outer) had the same cultivar growing on each side, whereas the other harvest row (inner) had the same cultivar growing on one side and the second cultivar growing on the other side.

The difference in yield between the inner row and the outer row for each split plot (cultivar) was determined for the first 2 yr of the study. A paired *t*-test of this difference using data from each split plot indicated no significant yield difference between the inner row and the outer row in 1983, 1984, or for both years combined (Table 5). This observation suggests that the experimental design used in this study was valid in that cultivars Amsoy 71 and Williams 82 were grown side-by-side without significant competitive effects on yields.

Seed yields and statistical analysis for each of the years of the study are shown in Table 6. In 1983 there was a significant decrease in yield of Amsoy 71 with increasing rainfall acidity as determined by a pH linear contrast analysis. The treatment response function of seed yield vs. treatment pH for this year was $y = 3463 + 157x$, where y is seed yield in kg ha^{-1} and x is the pH of the simulated rain (Fig. 1). The pH 3.0 treatment resulted in the lowest yield for this year and in 1984. These results support earlier work for this cultivar (Evans et al., 1981). However, in contrast to the results of Evans et al. the linear contrast was not significant in either 1984 or 1985. While the pH linear contrast was not significant in 1985, yield of the control (pH 5.6) was slightly lower than the yield for any of acidified rainfall treatments. These results suggest that the effects of acid rain on soybean yield are relatively small and are not necessarily consistent from location to location or year to year. The reasons for the difference in response are not clear, but the 1983 growing season had considerably higher temperatures and evapotranspiration rates (Banwart et al. 1987). In spite of the climatic stresses, however, the average soybean yield for Amsoy 71 was slightly higher in 1983 than in

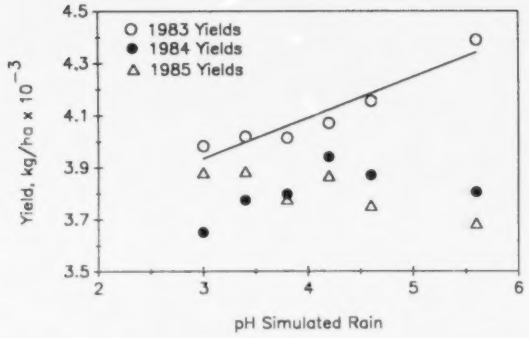

Fig. 1. The seed yields for Amsoy 71. The treatment response function for 1983 data $y = 3463 + 157x$ where y is yield in kg ha^{-1} and x is the pH of the simulated rain.

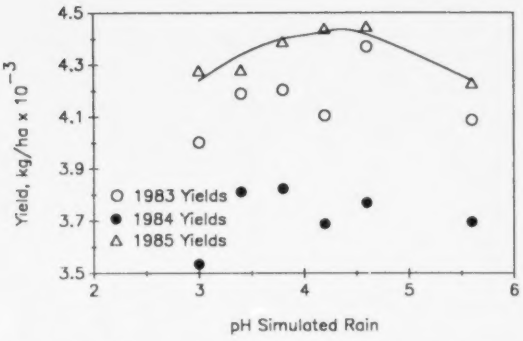

Fig. 2. Seed yields for Williams 82. For 1985 the treatment response function is $y = 2367 + 958x - 111x^2$, where y is yield in kg ha^{-1} and x is the pH of the simulated rain.

the other 2 yr. Using the linear equation from 1983 one can calculate the effect of different rainfall acidities on yield. If there were a 50% reduction in the acidity of ambient rainfall in central Illinois, the average annual pH of the rain would rise from 4.3 to 4.6 and the predicted seed yield for Amsoy 71 from the equation given would increase by 47 kg ha^{-1} or 1.1%. As a "worst case" example one might consider a 50% increase in the acidity of ambient rainfall in central Illinois. In this case the average annual pH of the rain would decrease from 4.3 to 4.1 and the predicted yield for Amsoy 71 would decrease by 31 kg ha^{-1} or 0.8%. Obviously these changes are quite small and the data for 1984 and 1985 would not suggest any significant changes in the yield of Amsoy 71, which has been suggested as one of the more sensitive cultivars.

While the statistical trends observed for Williams 82 are somewhat different than for Amsoy 71, the magnitude of yield reductions from pH are similar. None of the contrasts for Williams 82 were significant ($\alpha = 0.10$) in 1983 or 1984, whereas the quadratic trend was significant in 1985. The yield response patterns appear similar for all 3 yr (Fig. 2). The treatment response function for 1985 is $y = 2367 + 958x - 111x^2$. Using this equation, a 50% reduction in the acidity of ambient rainfall in central Illinois would result in a predicted increase in seed yield of 0.1%, a 50% increase in acidity of ambient rainfall would result in a decrease of 0.2% in seed yield of Williams 82. From a practical point of view these changes are extremely small in relation to yield variation caused by other factors such as disease, insects, or drought that occur from year to year. Results from the analysis of the 1983 and 1984 data suggest that yield of Williams 82 is unaffected by rainfall pH within the range of acidities tested. As was the case for Amsoy 71, the pH 3.0 treatment resulted in the lowest yields for Williams 82 in 2 of the 3 yr of this study. Unlike Amsoy 71, the highest average yields for Williams 82 were in 1985 when a quadratic contrast was significant. The pH 3.0 treatment resulted in the lowest value for both varieties when a weighted mean was calculated for all 3 yr (Table 6).

It should be noted that only two cultivars of soybean were used in the studies reported here. One of these, Amsoy 71, has been suggested as sensitive to acid rain (Evans et al., 1983). Preliminary evidence from additional field studies by the authors suggests the sensitivity of Amsoy 71 and Williams 82 are representative of several other cultivars of soybean.

Table 6. Seed yields for the six simulated rain treatments and the level of significance for selected contrasts.

	Amsoy 71				Williams 82			
pH treatment	1983	1984	1985	Weighted avg†	1983	1984	1985	Weighted avg†
	kg ha^{-1}							
5.6	4390	3806	3685	4039	4087	3697	4229	3989
4.6	4156	3871	3753	3971	4370	3770	4447	4190
4.2	4071	3941	3867	3982	4104	3689	4439	4040
3.8	4014	3798	3777	3889	4204	3823	4389	4118
3.4	4018	3775	3884	3907	4190	3812	4281	4084
3.0	3982	3652	3880	3849	4022	3536	4278	3917
Avg	4105	3807	3808		4163	3723	4344	
Contrasts				Level of significance				
pH linear	0.01	0.27	0.11		0.65	0.89	0.97	
pH quadratic	0.39	0.11	0.86		0.11	0.33	0.06	
3.0 vs. rest	0.24	0.12	0.42		0.18	0.12	0.47	
5.6 vs. rest	0.01	0.90	0.18		0.47	0.66	0.21	

† Each pH treatment was replicated 12 times in 1983, nine times in 1984, and six times in 1985. CV for yield was 9.60, 7.44, and 5.81 in 1983, 1984, and 1985, respectively.

CONCLUSIONS

Acid rain appears to reduce the yield of some soybean cultivars slightly but this effect is not consistent from year to year. Soybean treated with pH 3.0 rain from planting to harvest resulted in yields for Williams 82 and Amsoy 71 of approximately 3 and 4% below the yield for all other pH treatments combined. However, while rainfall of pH 3.0 is recorded occasionally in Illinois, the average annual pH of rainfall is approximately 4.3 and average annual pH in eastern North America is approximately 4.1 or higher. Calculations from data reported in these experiments have shown that even with an increase in rainfall acidity of 50% the predicted yield decrease for Amsoy 71 and Williams 82 would be less than 1%. Similarly the expected increase in yield of these soybean cultivars would be less than 1% if acidity in the rainfall were reduced by 50%. While there may be many beneficial or detrimental effects of reduced S and N oxide emissions, these results suggest lower acidity levels in rainfall are not likely to result in noticeable changes in yield of soybean.

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